Maintenance of *Balanites aegyptiaca* scattered trees for improving sesame (*Sesamum oriental*) grain yield and soil properties in lowlands of Tigray, Ethiopia

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ABSTRACT

A species of dryland tree called *Balanites aegyptiaca* provides numerous environmental and socioeconomic benefits. Those trees are cultivated by agriculturalists in their fields in lowlands of Tigray, but there was insufficient scientific data on how *Balanites aegyptiaca* trees affected the study area's soil characteristics and sesame yields. The purpose of this study was to look into the behavior of *Balanites aegyptiaca* to improve sesame yields and soil properties in Kafta-Humera District. Two variables were utilized to think about soil physicochemical properties and collect 48 pooled tests: separate from the tree trunk at four levels and soil profundity at two levels, reproducing the RCBD calculate framework on six trees. To study sesame yield, four-level log spacings were used, replicated six times. In addition, ANOVA was used to determine sesame seed yield and soil physicochemical properties. The outcomes demonstrated that the sesame seed yield was significantly (using $p<0.05$) from the *Balanites aegyptiaca* tree. Under the canopy as opposed to outside of it, and in the topsoil as opposed to the subsoil layer, the BD was significantly ($p<0.05$) lower. Findings for additional soil chemical parameters, including pH, OC, total N, available P, K, Ca, and CEC, showed a significant ($p<0.05$) increase in the crown area relative to the field and surface area over the subsurface layer. Under its canopy, the multipurpose tree *Balanites aegyptiaca* generally improves soil fertility; when grown on agricultural land, it can also boost soil and plant productivity in drought-prone areas when managed properly.

Keywords: Tree canopy; Soil properties; Sesame; Yield; Multipurpose tree; *Balanites aegyptiaca*; Low lands; Tree intercropping; Agroforestry.

1. Introduction

1.1. Background and justifications

Balanites aegyptiaca an evergreen, woody & thorny flowering tree about ten meter tall, belonging to the family *Zygophyllaceae* and native to tropical Africa (Chevalier *et al.,* 2003 and Groom, 2011). It is collectively known as the desert date and "*Meki'e o Bedano*" (Tigrinya) (Manji *et al*., 2013).

Agroforestry is one of the environmentally friendly methods that ameliorate and test smallholder soils (Schaller *et al.*, 2017; Fahmi *et al*., 2018). Agroforestry has numerous temporary, nonsupervisory and artistic services (Ranjith *et al*., 2017). Trees are means for organic husbandry to give attention to food security challenges for growers due to its advantages in guarding environmental declination, reducing external input cost and doing this assure agrarian sustainability (Zeynab *et al*., 2017).

Soil fertility reduction becomes a major constraint in increasing crop production and chemical inputs take as one cause for fertility loss (Chandini *et al.*, 2019). A high chemical input farming system also challenging sustainable agricultural productivity of lands (zhang *et al.*, 2018). Inorganic fertilizers are less profitable and risky for the environment (Ehui and Pender, 2005). all the artificial application with least studied agricultural lands and untrained agriculturalists may lead to permanent soil depletion; high farming inputs are also a main cause of wider environmental problems and damage of biodiversity on farmland (Paracchini , 2007). Therefore, agroforestry is one of the best solutions for the problem. While also *Balanites aegyptiaca* as an agroforestry tree has a role to play.

Parkland agroforestry, a system that integrates tree species into agricultural land, provides productive, protective, and economic functions that can advance the livelihoods of society, specifically small farmers (Bekele *et al.,* 2018).

This is widely recognized and important measures have been implemented to sustainably increase agricultural productivity at farm level, with particular attention paid to maintaining and improving existing practices and incorporating multiuse trees into farms (castle, 2021). Many studies in Ethiopia indicate decreases in bulk density, rises in available phosphorus, total nitrogen, and CEC, which are meaningfully higher under the tree canopy than in nearby open agricultural land of *Acacia polyacantha* (Birhane *et al.,* 2018), *Faidherbia albida*, *Acacia tortilis* (Desta, 2018) and *Acacia saligna* (Gebretsion *et al.*, 2019).

The conservation of isolated species of *Balanites aegyptiaca, Ziziphus spina-christi* and *acacia* on agricultural land and farms is common practice in the Tigray lowlands. Therefore, studying the impact of existing native MPTs on soil fertility is crucial to encourage individual farmers to continue planting trees (Jiregna *et al*., 2005). Previously, several studies were conducted on *Balanites aegyptiaca* tree species for medicinal use, fruit production and their impact on other countries (Kamal *et al.,* 2015), and the impact on sorghum yield was not significant in these countries and outdoors (kassa *et al*., 2010), but the effect of this tree species on sesame yield and soil physio-chemical properties was limited in Tigray. For example, Kassa *et al*., (2010) made a study of *Balanites aegyptiaca* on sorghum, but did not refer to sesame. Therefore, research is being carried out to fill these gaps. This research aims to study the conservation of the scattered *Balanites aegyptiaca* tree to improve sesame seed yield and soil properties in agricultural farm in the Tigray lowlands.

2. Methods

2.1. Study area

Kafta Humera district is located in western Tigray national regional state in north western Ethiopia (Figure 1). According to Alemu *et al.* (2015) Kafta-Humera lies between 36027'4.7" and 37033'7.1"E and 13039'45" and 14026'34.9" N, with an elevation between 560 and 1849 m a.s.l. The average annual precipitation is 645 mm and falls from June to September (Fig. 2). While the average low temperature ranges from 17.78 °C in January to 25.05 °C in April, the average high temperature ranges from 32.31 °C in August to 42.52 °C in May.
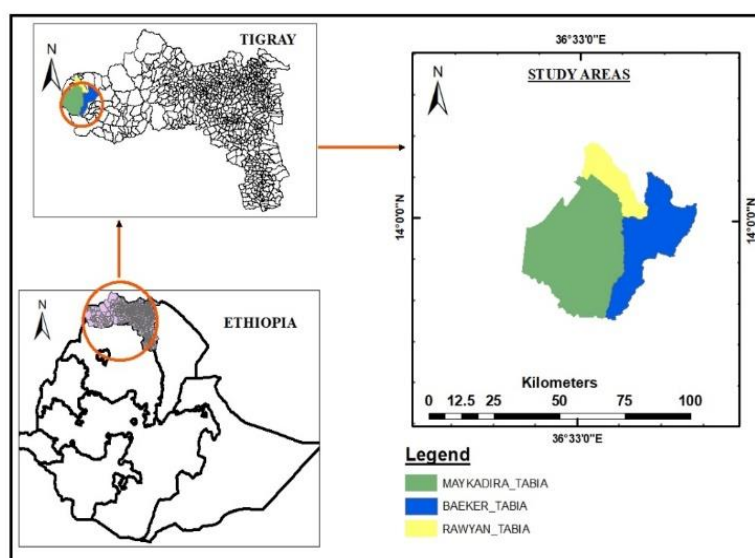
Figure 1. Study area location
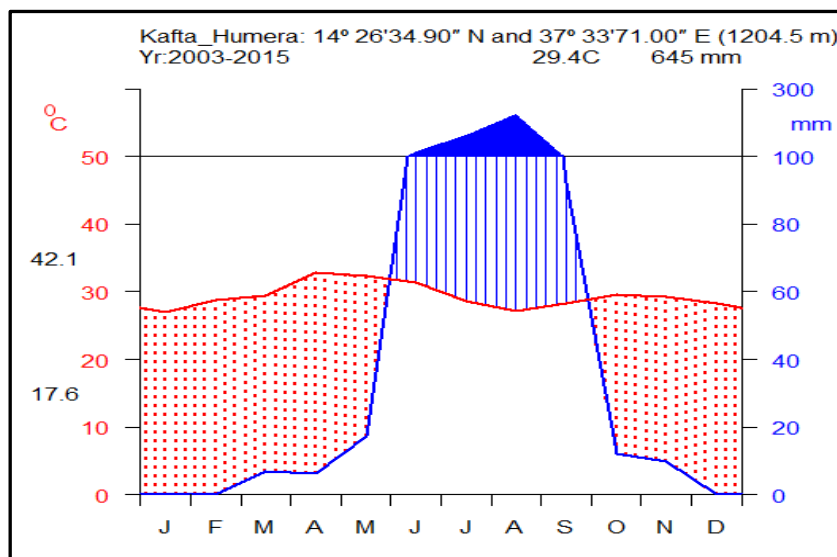
Figure 2. Kafta Humera climodiagram

According to Friis *et al.* (2011), there are three primary types of foliage in the study area: *combretum-terminia* timbers, *acacia-commiphora timbers, and alluvial timbers. Balanites aegyptiaca, Diospyros mespiliformis, Adansonia digitata, Acacia Senegal, Acacia abyssinica, Acacia polyacantha, Tamarindus indicia, and Ziziphus spina-Christi* are the woody species that are most frequently observed. A mixed husbandry system dominates by open crop husbandry. numerous growers (68.8) are rehearsing mixed cereal- beast husbandry, while 28 cultivated periodic crops and 3 beast parenting (CSA, 2013). The frugality of the quarter is substantially placed on the product of cotton and sesame as the primary cash crops. Beast parenting is another important exertion in the study area which includes cattle, scapegoat, lamb and burros. Tapping goo and incense trees also give cash income for original occupants (Selamawi, 2017).

2.2. Study designs and data collection methods

2.2.1. Tree selection for the crop yield and soil studies

Two-stage sampling, the tabia (the smallest local administrative unit) and the plot test were used to select the plots. Within the district, three kebeles were selected based on the occurrence of *Balanites aegyptiaca* trees.

Table 1. Characteristics of *Balanites aegyptiaca* for soil samples and for grain yield study

| Tree | DBH(Cm) | CD (M) | H (M) | Geographical Position | | |
				X	Y	Z
1	54.14	11.05	7.95	238483	1563663	392
2	55.41	10.9	7.95	238427	1563774	594
3	54.45	10.55	7.5	238480	1563220	592
4	57.32	10.7	7.8	238414	1563101	593
5	55.73	10.4	8.1	238339	1563417	594
6	56.05	10.4	8.4	238378	1563516	595
Mean ±SE	**55.52 ± 0.93**	**10.66±0.11**	**7.95±0.28**			

Where DBH = Diameter at Breast Height CD=Crown Diameter H=Height SE = Standard Error.

2.2.2. Sesame grain yield sample design and data collection

For the sesame yield and yield characteristics of the sesame trial, the distance to the tree trunk of *Balanites aegyptiaca* was taken into account. Distance was considered at four levels; i.e., within 0.5m (closed (A)), 2.5m (mean crown radius (B)), 5m (marginal crown radius (C)) and 15m in open land. These treatments were organized into a six-way randomized complete blockade (RCBD) design.
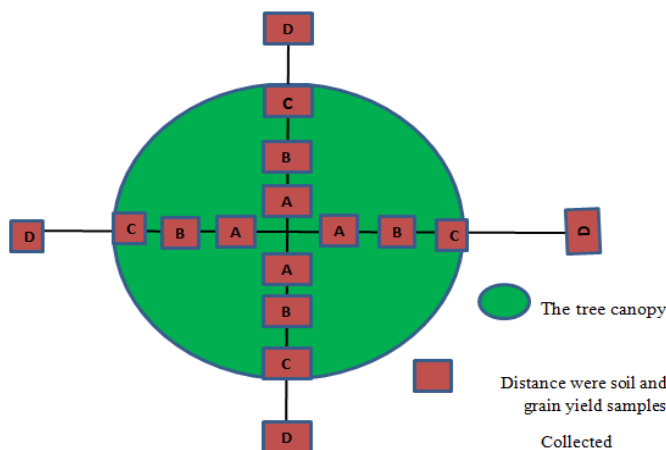
Figure 3. On-farm grain and soil sample plot design (Birhane et al., 2018)

Where, A = 0.5m, B=2.5m, C=5m, and D=15m from distance from tree trunk.

A total of four quarters (1 m^2 each) were placed under and outside the canopy according to Hailu *et al.* (2018) and Muhammad *et al*. (2018b) in four directions for the trunks of the examined trees. Data on sesame plants was collected in each quadrant. Plant height, number of capsules per plant, number of plants, number of branches, and height of capsule bearing zone were measured via meter tap from 5 randomly selected sesame plants in the quadrant. Grain yield and biomass yield per plot and per hectare per quadrant were measured at harvest time. Biomass was measured by harvesting the sesame crop from 1m^2 plots. Sesame harvest index was calculated as a percentage of grain yield in relation to total biomass yield (Donald *et al.,* 1976) and was expressed as such.

$$\text{HI (\%)} = \text{grain yied/total above ground biomass (grain + straw)} * 100 \qquad (1)$$

2.2.3. Soil sample design and data collection

The distance factor had four levels; near within 0.5 m, the radius of the center of the crown (2.5 m), the radius of the crown edge (5 m) and three times the total radius of the crown of the tree trunk (15 m) used as a control according to the method (Birhane *et al,* 2018; Mohammed *et al*. 2018b). The depth factor had two levels: 0-20 cm and 20-40 cm, representing the top and bottom soil layers in that order. The factors were organized into a factorial treatment system in the RCBD, which was replicated six times for soil trials.

Using conventional techniques, 48 samples were extracted from the study plots at two depths (Hartz, 2007; George et al., 2013). The Shire Soil Research Center's soil laboratory analyzes the following parameters: Soil Moisture (MC), Particle Size Distribution, pH, Electrical Conductivity (EC), Organic Carbon Substance (OC), Total Nitrogen (TN), Available Phosphorus (P), Cation Exchange Capacity (CEC), and Exchangeable Bases (K, Mg, and

Ca). Using core drill samples of undisturbed soil, the bulk density of the soil was calculated (Grossman and Reinsch, 2002).

2.2.4. Soil laboratory analysis procedure

2.2.4.1. Sample preparation

Air drying: Prior to analysis soils allow air drying (to avoid excessive soil drying where the availability of most nutrients and microbial biomass affected (George *et al.*, 2013) on paper to prevent microbes from mineralizing soil organic matter that can cause less accurate result.

Crushing and sieving: In order to reduce the heterogeneity of samples and to prepare for chemical reaction clods of sample soil were grind with wooden mortar, after removing all pebbles and organic residue which > than 2mm diameter (which weight and record solely), and sieve with 2mm sieve. Detailed analysis is done with the one <2mm size.

2.2.5. Laboratory analysis techniques

The soil pH of the soil samples was measured using a pH meter set to a soil/water ratio of 1:2.5. The total nitrogen (TN) was determined using Kjeldahl acid digestion (Jackson, 1958); the available phosphorus was determined by spectrophotometric absorption (Olsen, 1954); the soil's electrical conductivity (EC) was measured using a conductivity meter; the soil's cation exchange capacity (CEC) was determined after soil extraction by the ammonium acetate method at pH 7; the soil bulk density (BD) was determined using the oven drying method (Brady & Weil, 2002); the water content (MC) was determined using the gravimetric method (Blake & Hartge, 1986); the texture was determined using the hydrometer method (Gee and Bauder 1986). Bulk densities were computed using oven and weighing data.

$$\text{Bulk density(BD)} = \frac{\text{mass of oveen dry soil}}{\text{total volume of the soil}} \qquad (2)$$

$$\text{Moisture content} = \frac{\text{wt wet soil (g)} - \text{wt oven dry soil(g)}}{\text{wt oven dry soil(g)}} \qquad (3)$$

2.3. Data analysis

Collected data were compiled and prepared using the Excel 2021 computer program and investigation was made using R software version 4.3.1. One-way and two-way ANOVAs were used dependent on the nature of the data and the hypothesis being tested. A one-way ANOVA and two-way ANOVA were used to analyze sesame yield and soil properties respectively. The data was examined for signs of coming from a normally distributed population using the Shapiro-Wilk normality test. To determine whether the variance scores for each group were the same, Leven tests were employed to assess homogeneity of variance. Using Pearson correlation, correlation analyses were performed to evaluate particular physico-chemical properties of the soil. To determine whether there was a natural differentiation in the soil properties and yield, a multivariate analysis involving clustering and PCA (principal component analysis) was conducted using the associated data gathered using past v.3 (Hammer *et al.*, 2001). The significant means were separated using Tukey's test.

3. Results and Discussion

3.1. The influence of the *Balanites aegyptiaca* tree on sesame growth and grain yield

Result of the studies showed that sesame grain harvest (p < 0.001) and biomass product (p < 0.003) differed meaningfully under the shade of *Balanites aegyptiaca* compared to open ground without tree cover (Table 2). Similarly, plant height (PH), length of the capsule bearing zone (LCBZ), number of seeds per capsule (NSPC), and harvest index (HI) were also statistically significant (p<0.001) with radial distance (i.e., 0.5m, 2.5m, 5m and 15m) away from the tree trunk. Nevertheless, neither the number of plants per square meter (SC/M2) nor the number of branches per plant (NBPP) was statistically significant (p > 0.05).

Table 2. Mean values of sesame grain yield (Qu/ha) at different tree radial distances as influenced by *Balanites aegyptiaca* tree using
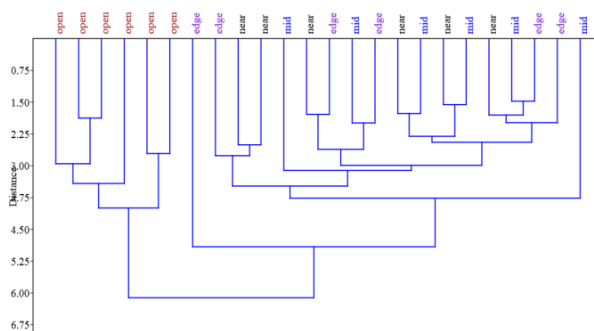
	Radial distance (m) from tree trunk						
	O.5M	2.5M	5M	15M	CV (%)	$LSD_{0.05}$	P-Value
PH (cm)	150.08± (5.76) [a]	148.91± (3.47) [a]	148.21± (5.35) [a]	132.58± (8.91) [b]	4.27	7.45	***
NBPP	3.37± (0.30)	3.29± (0.24)	3.16± (0.49)	3.041± (0.36)	1.02	0.44	NS
LCBZ (cm)	65.08± (1.73) [a]	65.54± (2.75) [a]	64.87± (2.45) [a]	55.37± (1.25) [b]	3.4	2.57	***
NCPP	70.83± (2.96) [a]	70.41± (1.77) [a]	66.16±(2.86) [b]	62.08±(4.2) [c]	4.96	4.02	***
NSPC	65.75± (1.39)	65.5±(2.20)	64.67±(1.73)	64.21±(1.50)	2.67	2.09	NS
SC.	25.37± (0.54)	25.41±(0.41)	25.5±(0.65)	25.16±(0.54)	2.13	0.65	NS
Yield (Qu/ha)	5.29±(0.11) [a]	5.22±(0.22) [a]	5.11±(0.27) [a]	4.47±(0.24) [b]	4.44	2.68	***
BM(Qu/ha)	39.77±(0.5) [a]	39.47±(0.76) [a]	39.07±(0.75) [a]	36.32±(0.66) [b]	2.13	0.99	***
HI	0.134±(0.002) [a]	0.131±(0.004) [a]	0.13±(0.005) [a]	0.123±(0.005) [b]	3.73	0.0058	**

Treatments within the same letters were not significantly different at p<0.5. where, *= p<0.5, ** = p<0.01, and *** = p< 0.001.

The harvesting index (HI) value was higher under the tree shade (13.7%) than in outside of the tree canopy (12%), where there was a 12.4% increase. For this reason; the result indicates a higher grain product under the tree shade than outside. overall means of the number of capsules at distances of 2.5 m and 5 m below the canopy showed significant fluctuations in the open field (p<0.0001). Likewise, the mean capsule score was higher under the canopy (70.83 per plant) at a canopy radius of 0.5 m and lower (62.08 per plant) at the open land which was lesser with 12.4%. Likewise, the mean length of the capsule bearing zone at a radial of 0.5 m from the tree trunk was greater (65.08 cm) than the open zone (55.37cm). Sesame seed yield decreased significantly and progressively with increasing distance from the stem (Table 2). The maximum sesame seed yield values were measured under the tree canopy at a radial distance of 0.5m, 2.5m, and 5m from the trunks, and these values decrease at a distance of 15 m outside the trunks. Grain yield was higher by15.5% at 0.5m radial distance from canopy than outdoor*s*. The results showed that the factory grown under the cover of *Balanites aegyptiaca* had a lesser advantage than the open field (15 m) of the tree caddies. The significant result in grain product under the tree canopy might be due to bettered soil parcels in the tree canopy cover compared to open fields. Soils below the cover were richer than soils outdoors, owing to increased buildup of soil organic matter, nitrogen obsession and nutrient cycling by trees (Desta, 2018).

Trees have an ability to recover soil water holding and organic matter due to the adding of covering and root rot, lower the amount of evaporation from the soil's surface under the shade, improve nutrient cycling, and improve nitrogen fixation (ladha *et al.,* 2019). Fertility and humidity were better under the canopy than outside the canopy; the average grain yield under the canopy was higher than in the open growing area. Also due to the low competition between the *Balanites aegyptiaca* tree and the Sesame plant during soil fertilizer application at different depths of the soil layer and the poor lateral rooting properties of the tree (Negayo, 2018). Consistent with the current study, Eldin and Fadl (2014) reported higher yields of peanuts, sesame and rosella under the canopy of *Acacia Senegal* and *Balanites aegyptiaca* trees compared to open land cultivation in Sudan. Furthermore, the current result is also in line with higher yields—101% for sorghum in Welinchiti, 67% for corn in Buta-Jira, 40% for wheat, and 12% for rye—under the tree crown as opposed to the tree's open-air yields. (Teff) to Mojo and increased maize yields by 76% and sorghum yields by 36% of Hararghe under the *Faidherbia albida* tree canopy (Poschen, 1986). Similarly, Gebru (2018) reported decreased field in southern Ethiopia and increased maize yields among *Faidherbia albida* and *Croton macrostachyus*. Similar to this, Desta (2018) also found that wheat grain yields under the *Faidherbia albida* and *Acacia tortilis* tree crowns were higher than those under the open tree crown.

The mean above-ground biomass yield (BMY) sesame harvested at the varying separations from the trunk of the tree, were statistically weighty (p<0.05). In overall, the outcome of an analysis indicated that, mean biomass was decrease as remoteness from the tree trunk. The BMY value at open land was lower by 6.8% when compere with BMY value under tree canopy. The case of varying the radial distance between the logs and the open ground was similar to the grain yield described above. The function of Balanites aegyptiaca on the ground beneath its canopy was the cause of the biomass differential in the fertility gradient. While some researchers found that intercropping sorghum with *Acacia albida* increased sorghum productivity and biomass yield significantly below the tree canopy compared to open areas. When compared to open farmland, Kho *et al.* (2001) found that pearl millet (Pennisetum glaucum) produced 36% more dry matter when grown under canopy. Comparably, *Prosopis juliflora* and *Acacia tortilis* tree canopy cover results in higher biomass outputs than open regions (Kahi *et al.,* 2009). Its advantageous effects may be attributed to the tree's root system and its capacity to enhance the soil. such that the near, mid and edge radial distance making up the first cluster and open field as the second cluster. The hierarchical clustering shows grain yield under the tree canopy and open land has significant difference.


Figure 4. Dendrogram results from UPGMA method of hierarchical cluster analysis
(A for four radial distance of grain yield)

Where near=0.5m, mid= 2.5m, edge=5m, and open=15m distance from tree trunk.

A multivariate method called cluster analysis attempts to categorize a sample of subjects based on a set of characteristics measured in various groups that are comparable enough that homologous individualities belong to the same group (Cornish, 2007).

The cluster analysis separated the *Balanites aegyptiaca* tree effect on four radial distances with Euclidean diversity distance ranging from1.4 to 6 (Figure 4). The Dendrogram was divided into two main clusters the first cluster was near, medial, edge and the alternate cluster open. Generally, the hierarchical clustering analysis shows significant differences between results of sesame grain yield and attributes under the cover and open cultivated. This is analogous with the ANOVA result.

Principal component analysis (PCA) showed that two components accounted for 71.01% of the total variability, which could be explained by all features of the effect of *Balanites aegyptiaca* tree on sesame seed yield (Figure 6). The first component accounted for 56.38% of the variance, the second component explained 14.63% of the total variability.
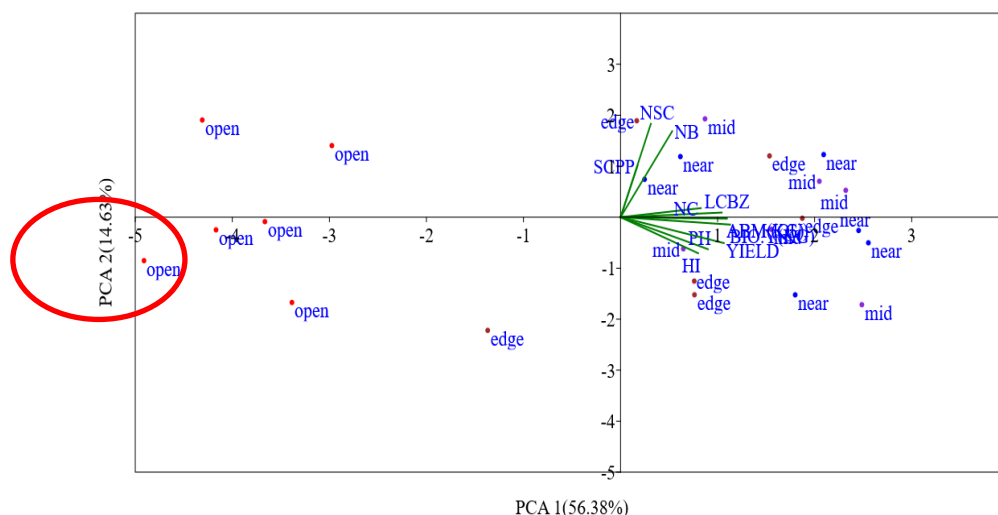
Figure 5. PCA of sesame grain yield and yield component values based on radial distance of *Balanites aegyptiaca* tree and open land

Where near=0.5m, mid= 2.5m, edge=5m, and open=15m distance from tree trunk.

The PCA analysis again shows that the grain yield is overall different in the open, while we see overlap in areas occupied by the near, middle and edge areas with respect to grain yield. This coupled with the overall analysis in this chapter shown above, with confidence we can say that *Balanites aegyptiaca* tree is positively affecting the grain yield and technologies to allow the combination of both *Balanites aegyptiaca* and Sesame is needed. According to this research, Baraki (2015) reported on the agronomic traits of five distinct genotypes of sesame (Sesamum indicum L.) based on grain yield cluster analysis.

3.2. Influence of *Balanites aegyptiaca* Tree on selected soil properties

3.2.1. Soil Texture

Balanites aegyptiaca influences soil particle size distribution (PSD), bulk density (BD), and moisture content (MC) at different radial distances from the tree stem and at soil depth, according to the variance analysis result (Table 3).

Table 3. Mean (±Sd) values of BD (g/cm3), SMC (%) and soil particle sizes (%) at different tree radial distances from trunk of *Balanites aegyptiaca*

Parameter	Depth	Distance (m) from the trunk						
	(Cm)	0.5	2.5	5	15	CV%	LSD$_{0.05}$	P-Value
BD (g/cm^3)	0-20	1.12±(0.06)^b	1.23± (0.06) ^{b}	1. 2± (0.02) ^{b}	1.423±(0.14)^a	6.76	0.11	**
	20-40	1.22±(0.09)^b	1.27±(0.09)^{ab}	1.38±(0.12)^a	1.35±(0.07)^a	7.41	0.11	*
SMC (%)	0-20	15.12±(0.61)^a	14.9±(2.85)^a	14.17±(1.41)^a	11.49±(2.84)^b	7.38	1.23	***
	20-40	11.82±(0.92)^a	11.78±(2.07)a	11.82±(3.24)a	11.61±(2.50)^a	13.24	2.5	NS
Clay (%)	0-20	53±(3.56)^a	53.33±(2.66)^a	53±(1.75)^a	51.83±(2.3)^a	4.28	2.72	NS
	20-40	52.5±(0.23)^a	52.27±(.31)^a	52.17±(0.22)^a	50.83±(0.43)^a	6.3	1.4	NS
Silt (%)	0-20	11.66±(3.44)^a	10±(1.32)^a	11±(1.32)a	10.65±(2.12)^a	11.3	2.74	NS
	20-40	9.24(1.6)a	11.16±(3.2)^a	10.66±(1.6)^a	11.03±(2.55)^a	13.3	1.8	NS
Sand (%)	0-20	35.83±(1.67)^a	36.67±(1.63)^a	36±(2.34)^a	38±(1.2)^a	3.77	1.66	NS
	20-40	37.83±(2.75)^a	36.33±(2.04)^a	37.17±(1.33)^a	37.67±(1.83)^a	4.88	2.2	NS

Treatments with the same letter are not significantly different at p < 0.05. where * = P< 0.05, **=p<0.01 and ***=p<0.001, NS=p>0.05,

There is no statistical difference, according to analysis of variance between the PSD at different radial distances from the trunk and soil depth (Table 3). The clay content (52%) dominates the sand (37%) and silt (11%) fractions that make up the clayey soil.

PSD is an important and enduring soil characterization and provides a general characterization of soil physical properties (Prasad and Power, 1997). Soil tests showed that *Balanites aegyptiaca* trees had no significant impact on PSD variability.

This means that PSD is more related to parental material and less influenced by management (Miller and Donahue, 1995; White, 1997). Similar to this study in Ethiopia Hailu *et al*., (2000) on *Faidherbia albida*; Yadessa *et al.,* (2009): in *Millettia ferruginea* and *Cordia africana*; Napisano (2017).

3.2.2. Soil Bulk Density

As the distance between the tree base and open ground and the depth of the subsoil grow, the mean BD values tend to rise (Fig. 7). This decline in BD beneath the canopy could be brought on by a higher buildup of organic stuff there than there is outside.

It is well recognized that adding organic matter to soil enhances its biological and physical qualities. In soil beneath tree canopies as well, organic matter increases porosity, which lowers bulk density. Similar to our study, isolated trees of *Croton Macrostachyus* and *Cordia africana* in Ethiopia showed a reduced BD (Mohammed *et al.,* 2018). Smaller BDs were also reported by Mancsur *et al.* (2014) under the *Faidherbia albida* and *Croton Macrostachyus* tree canopy, which are dispersed throughout the Umbulo Wacho River Basin in southern Ethiopia.
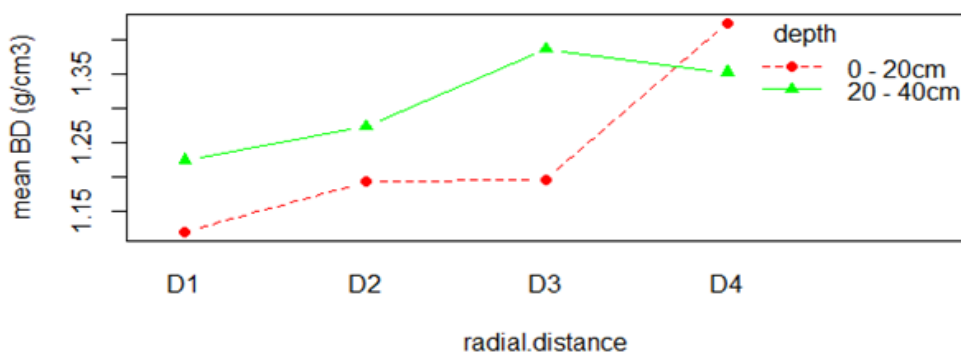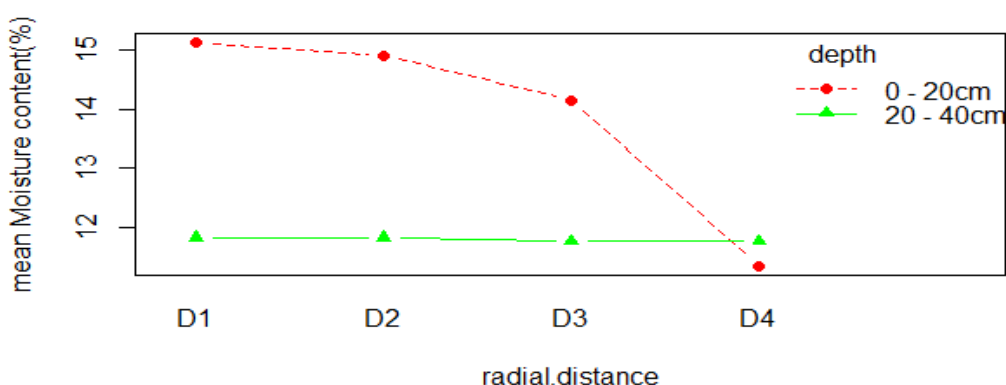
Figure 6. Soil BD at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

The results were consistent with reports of *Prosopis juliflora* and *Acacia tortilis* (Kahi *et al*., 2009). Differences between the surface (1.23 g/cm^3) and the subsurface (1.23 g/cm^3) were also observed.31g/cm^3) Soil can be due to the influence of root inputs, cultivation practices, and organic matter.

3.2.3. Soil Moisture Content

Subsurface soil layers showed the lowest mean values (11.6%) at a distance of 15 meters from open land and the greatest mean values (15.2%) at a canopy radius of 0.5 meters of the surface soil layer. As the soil depth and radial distances from the tree trunk grew, the results showed a diminishing tendency (Figure 7). The ability of the tree to maintain the ground moisture content by offering cover and lowering evaporation through its canopy, which raises the infiltration rate within the system, may be the cause of the advanced soil moisture content maintained beneath the trees' canopy (Kessler, 1992; Rhoades, 1995). Higher soil organic matter beneath the canopy and the mulching effects of the litter layer and shade, which lessen evaporation, could account for the higher moisture content (Moody and Jones, 2000).

Figure 7. Soil MC at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

This outcome was consistent with a study (Tadesse *et al.,* 2000) that discovered the soil moisture content of *Millettia ferruginea* trees was higher in subsurface soils (10%) and surface soils (19.6%) within the canopy zone than in surface soils (15.9%) and subsurface soils (8.9%) outside the canopy. Similarly, information about the *Acacia nilotica* tree was released by Mamo & Genet (2017).

3.3. Effect of *Balanites aegyptiaca* on Selected Soil chemical properties
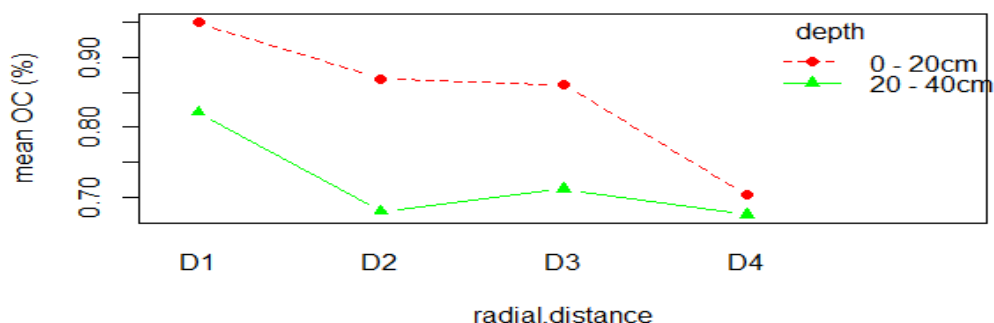
3.3.1. Soil Organic Carbon

The mean soil organic carbon (OC) levels in the open field and those below the tree canopy differed significantly (p 0.001) as the radial distance from the tree trunk increased, according to the data. In comparison to the surface (0–20 cm) and subsurface (20–40 cm) soil depths in the open field, the mean values of OC were higher in the soil depths beneath the tree canopies (Table 4).

Table 4. Mean (±Sd) values of selected soil chemical properties at different radial distance

Variables	Depth (cm)	Distance (m) from the tree trunk				CV	LSD$_{0.05}$	P-value
		0.5	2.5	5	15			
pH$_{(H2O)}$	0-20	7.51± (0.16)[b]	7.57± (0.16)[b]	7.74± (0.23)[ab]	8.01± (0.29)[a]	2.84	0.26	**
	20-40	7.67± (0.2)[b]	7.75± (0.11)[ab]	7.74± (0.18)[b]	7.99± (0.31)[a]	2.74	0.24	*
EC (dS/m)	0-20	0.13±(0.01)[b]	0.125±(0.04)[b]	0.133±(0.016)[b]	0.142±(0.02)[a]	14.55	0.025	**
	20-40	0.17± (0.008)a	0.14± (0,01)[b]	0.13± (0.012)[b]	0.144±(0.02)[a]	11.48	0.2	***
OC (%)	0-20	0.95±(0.05)[a]	0.87±(0.07)[a]	0.86±(0.07)[a]	0.7±(0.077)[b]	8.85	0.09	***
	20-40	0.82±(0.04)[a]	0.68±(0.07)[ab]	0.71±(0.06)[ab]	0.67±(0.07)[b]	13.57	0.011	**
Total N (%)	0-20	0.105±(0.31)[a]	0.093±(0.01)[a]	0.08±(0.006)[a]	0.058±(0.30)[b]	11.65	0.011	***
	20-40	0.082±(0.26)[a]	0.071±(0.03)[a]	0.078±(0.004)[a]	0.045±(0.01)[b]	14.3	0.011	***
Av. P (mg/kg)	0-20	6.32±(0.21)[a]	6.1±(0.30)[ab]	5.54(0.30)[bc]	4.76± (0.30)[c]	9.53	0.65	***
	20-40	5.41±(0.26)[a]	5.04±(0.36)[ab]	5.01±(0.36)[ab]	4.4±(0.36)[b]	13.22	0.91	**

According to Brady and Weil (2002), plant nutrition, soil fertility, biological activity, and the chemical and physical properties of the soil are all greatly impacted by organic matter (OM). OC was to determine the quantity of organic matter present in the soil. Under the cover of trees, the mean value of OC content was greater (0.95%) than on open plain (0.67%). Under the canopies of the distributed Balanites aegyptiaca trees, OC was higher than in an open field at both surface and subsurface soil depths by 26% and 18%, respectively. The range of OC content in the soil depth and radial distance was 0.65–0.95%, and it decreased to 0.05–1.5%, according to Tadesse *et al*. (1991). This received a middling rating.

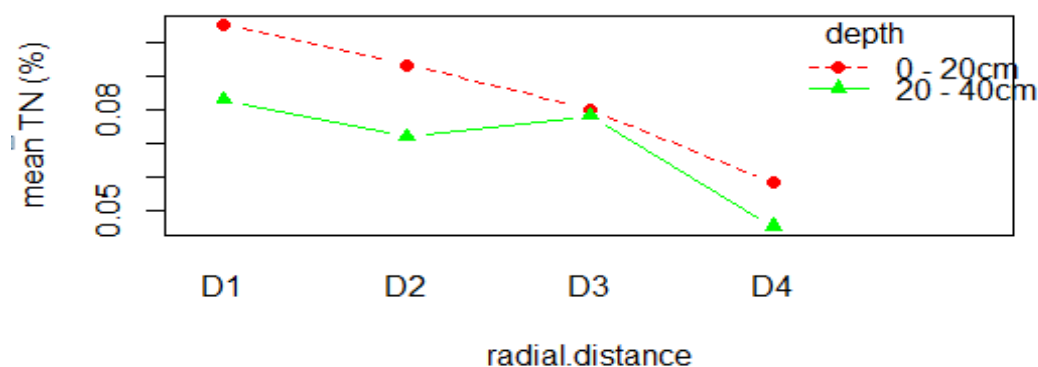**Figure 8.** Soil organic carbon at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from the tree trunk.

This result is in line with earlier research done at various sites in Ethiopia, where Asaye (2017) discovered that the SOC decreases with increasing distance from the tree trunk and moving from ground surface to subsurface depth.

Others, like Gebrewahid *et al.* (2019), also noted a gradual and significant decline in soil organic carbon (OC) with increasing distance from the tree bases of *Oxytenanthera abyssinica* and *Dalbergia melanoxylon* trees in the northern Ethiopian lowlands.

3.3.2. Total nitrogen

Between radial distances and soil depths, the overall mean total nitrogen (TN) values demonstrated a significant difference ($p < 0.001$) (table 4). In this investigation, the TN range was between 0.05 and 0.15 which falls into the middle category (Tadesse *et al.,* 1991). The highest mean results (0.09%) were obtained at the nearest distance from the tree trunk (0.5 m) and the lowest (0.058%) in the open field (15 m). Similarly, based on the soil depth, the TNs of the topsoil (0 - 20 cm) was statistically higher ($p<0.001$) than those of the corresponding subsoil (20 - 40 cm) at all radial distances. Regarding surface soil depth as a function of radial distance, mean values of TN in the canopy were statistically higher ($p<0.001$) than the mean value at open area. In addition, mean TN values in open areas at basement depth were significantly ($p<0.001$) lower than those in the first three radial distances. TN concentration under the canopy (0.5 m) was 53% and 13% larger than the open area and basement depth, respectively. Generally, the result shows a decreasing trend on mean TN values with increasing distance from the tree trunk to the open field, both at the soil surface and below the surface (Figure 10).

Figure 9. Total soil nitrogen at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

The cumulative result indicates a higher proportion of TN under the canopy than in the open growing area. TN is also related to the availability of organic carbon from leaf litter and the fine rotation of tree roots (Tilahun, 2007). The droppings of domestic and wild animals resting under the tree also contributed to the high availability of nitrogen under the canopy. Various results have been reported in accordance with this study. *Acacia seal* in a rift valley in Ethiopia showed 42% higher nitrogen availability near the base of tree than outside of the canopy; *Acacia tortilis* added 42% more nitrogen than the field (Tanga *et al.* 2014). A parallel result was reported from a study under the tree *Faidherbia albida*; Their report shows that as the distance from the tree trunk to the open ground increases, the TN decreases (Manjur *et al.,* 2014). This may be related to the high accumulation of waste from aboveground and belowground biomass. Furthermore, this result agrees with Abera Tesfaye & Lemma (2019) for *Acacia seyal*. They report a higher TN under tree canopy than in open, cultivated land. This may be due to a large influx of organic matter resulting from fine root degeneration and shedding of leaf litter, followed by microbial

activity under the tree canopy (Manjur et al., 2014). In contrast, Deng and Shangguan (2017) found a much lower proportion of TN in the *Acacia Seyal* cover crop system than in sorghum crops.

3.3.3. Soil Electrical Conductivity

In this research, there was a significant variation in the mean values of soil electrical conductivity (EC) across different radial distances, with a significance level below p0.05. The study further revealed a significant increase (p<0.001) in the disparity of mean soil organic carbon (OC) levels between open field areas and those beneath tree canopies as the distance from the tree base expanded. Additionally, the soil's surface layer (0 – 20 cm) and the layer just below it (20 – 40 cm), found under the tree canopies, exhibited higher average OC values compared to those in the corresponding layers of the open field (Table 4).

The data indicates a slight upward trend in the corresponding values as the distance from the tree trunk increases, as seen in Figure 10. The average soil electrical conductivity (EC) within the area under the tree canopy was found to be lower by 8.5% and 6.53% compared to the average EC values of the soil's surface and the subsurface layers in the open field, respectively. The measured EC values ranged between 0.13 and 0.14 dS/m for the surface soil, and between 0.13 and 0.177 dS/m for the subsurface soil layer. In both cases, the salt concentration, as indicated by EC, was notably low. This condition is often anticipated in areas with intensive agricultural activities, which tend to lead to a depletion of base-forming cations (Tilahun, 2007). Additionally, lower EC values were observed in the upper soil layer (0–20 cm) compared to the subsurface layer (20–40 cm), potentially due to the washing away of base-forming cations through rainwater and the impact of farming techniques (Tilahun, 2007).

The reduced soil electrical conductivity (EC) beneath tree canopies compared to the areas outside could stem from the greater accumulation of leaf litter above ground and the corresponding uptake of cations by the trees. According to Smith & Doran (1996), soil of any texture is deemed non-saline and appropriate for all types of crops if its EC is below 2 dS/m. On the other hand, soil is considered highly saline if its EC exceeds 8.1 dS/m.
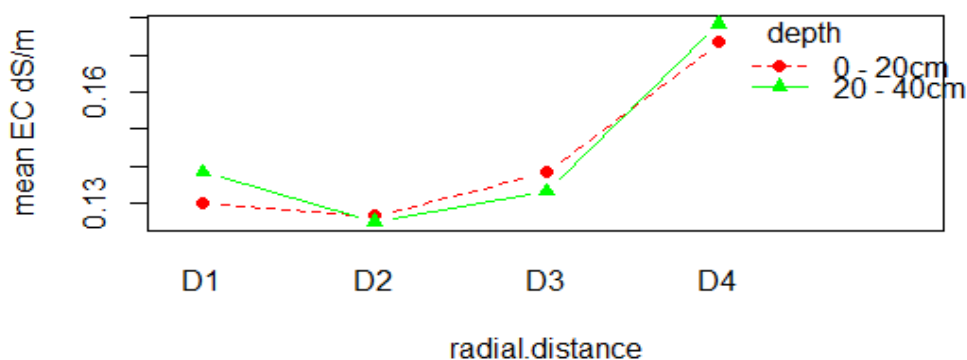
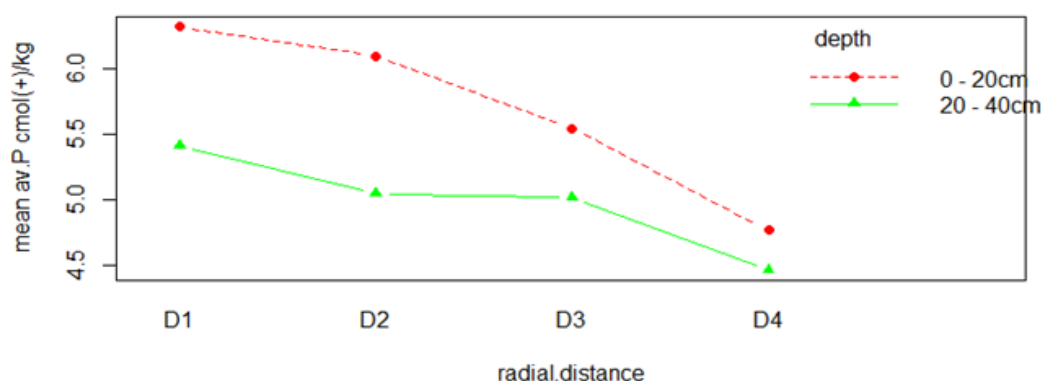**Figure 10.** Soil EC at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

In general, the mean EC value tends to increase from the tree trunk to the open agricultural area (Figure 11). The present result was similar for Berhe *et al*. (2013) who evaluate the effect of *Ficus thonningii* on soil physicochemical properties in Ethiopia and found a significant increase in soil EC when moving from the *Ficus*

thonningii tree base to open farms. Similarly, Gebrewahid *et al.* (2019) reported *Oxytenanthera abyssinica* and *Dalbergia melanoxylon* EC trees under the canopy having lower soil stands than outside.

3.3.4. Available Soil phosphorous

The aggregate, aboveground, and underground mean values of soil available phosphorus (Avg. P) differed significantly($p<0.001$) at all radial distances (.5 m> 5m> 15m) (Figure 12). Similarly, the results Av. P at the depth of the surface soil at all radial distances from the tree trunks were significantly larger($p<0.001$) than its subsurface soil depth. According to the current regulation, Av. The P under the cover of the *Balanites aegyptiaca* trees was largely fortified compared to the open area. The mean accretive face and underground values in the cover zone were 54.69 % above ground and 42.54% Av. P in relation to the separate above- ground and underground soil layers in the field respectively. The mean of Av. still, P observed at radial distance and bottom depth was (5- 7 cmol (+) kg^{-1}; this is the medium rate following (Olsen *etal*., 1954).

Figure 11. Soil Av. P at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

This higher mean P in topsoil compared to subsoil may be due to the relatively higher contribution of mulch to topsoil compared to removal of organic matter from topsoil by various forms of inorganic P fertilizer application. This finding was similar to Manjura *et al*. (2018), stated advanced an Av.P. under the canopy of *Faidherbia aldida* trees than the open ground. Furthermore, Komicha Negeyo Desta (2018) reported a higher amount Av.P. In Ethiopia's central Rift Valley, beneath the canopy of *Faidherbia albida, Acacia lebbeck*, and *Acacia tortilis*, as opposed to outside of it.

3.3.5. Soil reaction

Table 4 shows that there was a significant difference ($p = 0.05$) in the soil response (pH) along the log's horizontal radial distance, but not between soil depths. The farther away from the tree base, the higher the measured pH of the soil. The pH of the soil was marginally higher in open areas and lower beneath the canopy. The pH of the soil was lower at a depth of 0–20 cm than it was between 20 and 40 cm. The pH of the soil was 7.51 in the canopy compared to 8.01 in the field.

According to Tadesse et al. (1991), the pH of the soil varied from 7.5 to 8, with a mean of 7.75 for both the canopy and open areas. This pH range falls into the slightly alkaline category. The radial distance between a tree's base and

its open growing surface generally increases with the pH of the soil. This was caused by the trees' ability to buffer organic matter from the decay of dead roots and leaf litter, which decreased the alkalinity of the soil in the agricultural area. Similarly, lower soil pH levels beneath trees' canopy than in open fields could result from a number of processes in the tree that release H+ ions, including the tree's uptake (or depletion) of soil base cations and the breakdown of organic matter. This research supports the findings of Asaye's (2017) study on *Acacia tortilis* under various land use conditions in Oromia. Negeyo (2018) found that in a rift valley in the Oromia region, the pH of the soil was higher outside than it was beneath the canopy for *Acacia tortilis* and *Faidherbia albida*. Jiregna *et al*. (2005) discovered, in contrast to this finding, that the pH of the soil was not significantly different under the canopy of Cordia africana and Croton Macrostachyus from the field. In addition, Hailu *et al*. (2000) found that no significant horizontal or vertical differences in soil pH were observed among *Millettia ferruginea*.

3.3.6. Soil cation exchange capacity (CEC)

The results of the study indicate that there was a significant difference ($p<0.001$) in the average values of the cation exchange capacity (CEC) of the soil at the upper soil (0–20 cm) and subsurface (20–40 cm) of the soil, as well as its total values, throughout all radial distances from the trunk. Similarly, at all radial distances from the tree trunk, the mean values of the surface depth soil (0–20 cm) were significantly different ($p<0.001$), but not the corresponding subsurface soil depths ($p = 0.169$) (Table 5)

**Table 5.** Mean (±Sd) values of CEC and (K, Ca and Mg) at different radial distances and soil depth

Parameter	Depth (cm)	Distance (m) from the tree trunk				CV%	LSD$_{0.05}$	P-value
		0.5	2.5	5	15			
CEC	0–20	52.7± (1.9)[a]	50.38±(4.38)[a]	49.55±(4.36)[a]	41.93±(3.22)[b]	10	4.67	***
(cmol(+)/kg)	20-40	47.75±(3.6)a	47.58±(3.01)[a]	41.72±(6.16)[b]	48.33±(1.59)[b]	8.49	3.46	***
K	0–20	0.498±(0.03)[a]	0.46±(0.09)[a]	0.42±(0.08)[a]	0.29±(0.07)[b]	12.6	0.89	***
(cmol(+)/kg)	20-40	0.45±(0.02)[a]	0.40±(0.07)[ab]	0.36±(0.06)[b]	0.25±(0.05)[c]	14.9	0.06	***
Ca	0–20	11.25±(1.17)[a]	10.05±(0.89)[a]	10.13±(1.23)[b]	10.35±(0.65)[b]	10.5	1.34	*
(cmol(+)/kg)	20-40	9.73±(0.69)[a]	9.8±(0.56)[a]	9.4±(1.04)[ab]	8.22±(0.55)[b]	7.3	0.81	**
Mg	0–20	11.57±(1.5)[a]	11.41±(1.19)[a]	10.96±(1.3)[a]	9.55±(1.6)[b]	12.9	1.72	*
(cmol(+)/kg)	20-40	11.32±(1.4)[a]	10.64±(1.3)[a]	10.47±(1.1)[a]	8.40±(1.5)[a]	12.3	1.58	NS

CEC= Cation exchange capacity k= potassium Ca= calcium Mg = magnesium. Treatments with the same letter are not significantly different at $p<0.05$. Where * =$P< 0.05$, ** =$p<0.01$, and ***=$p<0.001$, NS=$p> 0.05$.

CEC is the ability of soils to absorb cations (Brady & Weil, 2002) and it indicates the nutrient holding capacity of a soil ; and used as a measure of soil fertility (Giachene and Kimaru, 2003). The maximum mean value of soil CEC (52.7cmol (+)/kg) was observed at 0.5m trees' radial distance from the trunk in the soil surface (0-20cm) while the minimum value (38.4 cmol (+)/kg) was recorded in an open field.

The research reveals significant differences in cation exchange capacity (CEC) values at different distances from tree trunks, with average values at surface and subsurface depths. CEC at open land is lower (33%) than under tree canopy (0.5m distance).

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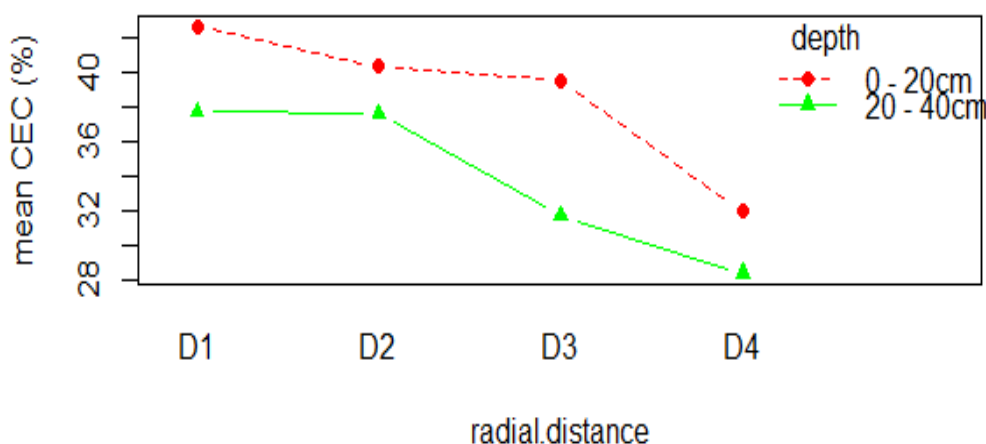
Figure 12. Soil CEC at a radial distance and soil depth

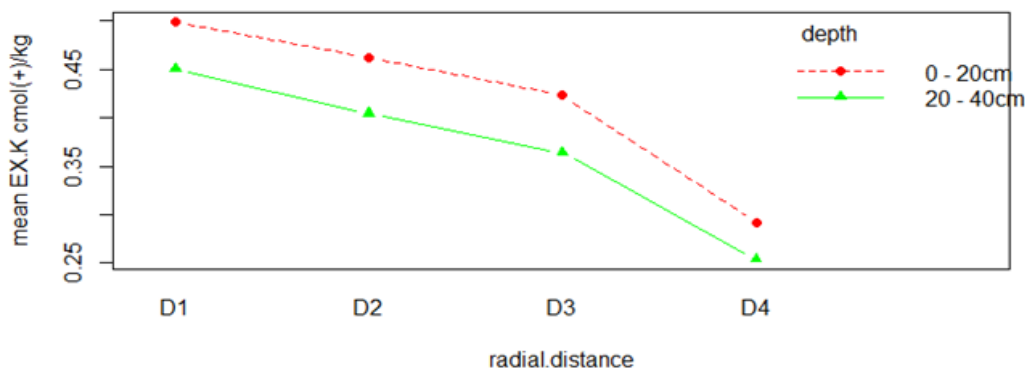Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

Overall, the data indicate a declining trend in CEC in the above- and below-ground soil layers as well as with soil depth as the radial distance from the tree trunk increases (Fig. 13). An increased buildup of organic matter at the tree's base could have been the cause of this phenomenon (Jones, 2001). This author claims that the total negative charge of the soil rises with the amount of organic matter beneath the tree canopy, increasing the soil's CEC. In line with this, Aweto and Dikinya (2003) found that under the canopy of *Combretum apiculatum* and *Peltophorum africanum* trees, there was a significantly higher soil CEC than outside the canopy. Molla & Linger (2017) for *Acacia decurrens*, Emire and Asfaw (2018) for *Ficus sur* and *Cordia africana*, and Zeleke Asaye Tiruneh (2017) for Acacia tortilis in other regions of Ethiopia have also reported a significant increase in soil CEC in the canopy compared to open land. Fertile soils have a CEC of >24 cmol (+)/kg, while those with a CEC of <16 cmol(+)/kg are regarded as unfertile (often highly weathered) (Giachene Kimaru, 2003; Hazelton and Murphy, 2007). which indicated that it had fertile soil according to (Gachen E. and Kimaru, 2003) rating (>24 cmol$^{(+)}$/kg). And for both canopy zone and open areas the rating was high, according to (Booker *et al.,* 1991) the range was fall of 38 - 52cmol (+)/kg.

3.3.7. Exchangeable Soil Cations

Table 5 shows significant variation in exchangeable base cations (Ca, Mg, and K) in soil depth and radial distance. As tree trunk distance increases, alkaline cations decrease. This is due to heavy litter accumulation beneath the canopy, resulting in more exchangeable cations in the forest canopy than in open areas.

3.3.8. Exchangeable Soil potassium

Exchange potassium (k) varied significantly (P<0.05) in the depth of soil from the surface (0–20 cm) to the subsurface (20–40 cm), as well as in the distance between the trunk and open soil (Table 5). Exchangeable potassium in surface soils reached its maximum values of 0.51 (cmol (+) kg-1) at a distance of 0.5 m. At 15 m from the treetop, the values drop by 41% to 0.29 (cmol (+) kg-1). In addition, the mean K value decreased with soil depth from 0.42 cmol (+) kg^{-1} to 0.36 (cmol (+) kg^{-1}), each by 14% with respect to depth from the soil surface. Overall, the K value was between 0.49 and 0.25, the mean was 0.37 and thus below the average value (FAO 2006).

Figure 13. Soil ex. k at a radial distance and soil depth

Where, D1=0.5m, D2=2.5m, D3=5m, and D4=15m distance from tree trunk.

Soil K shows a decreasing trend as the radial distance between the base of the tree and the open agricultural area increases (Fig. 14). Comparable to this finding, Abebe (2006) reported that in Hirna, the highest exchangeable potassium values for topsoil decreased by 2.01 and 2.13 (cmol (+) kg-1) in soil to 0.75 m to 1, respectively.28 and 1.18 cmol (+) kg-1 at a distance of 30 m *Cordia africana* and *Croton Macrostachyus* trees, respectively.

3.4. Pearson correlation analysis for soil physico-chemical properties

The relation between selected soil properties and OC, tree radial distance and soil depth were shown, that highly correlated and significant (P<0.05) except soil EC, pH and K with soil depth non-significant. Simple correlation analyses were carried out to determine the relationship between a few key soil physicochemical properties and the depth, organic carbon content, and distance from the tree trunk. The result showed that the percentage of MC, total N in soil, avg. P, K and CEC correlated positively and strongly (p<0.001) with percent soc. On the other hand, soil BD, pH and EC were negatively correlated with soil organic carbon content.

Table 6. Pearson correlation analysis for some selected soil parameters with SOC, distance and depth

Parameters n = 48	Correlation coefficient ®					
	Organic carbon		Distance		Depth	
Soil moisture	0.71	**	-0.38	**	-0.64	**
Bulk density	-0.48	**	0.61	**	0.29	*
Soil EC	-0.38	**	0.58	**	0.03	NS
Soil PH	-0.34	*	0.57	**	0.16	NS
Total nitrogen	0.66	**	-0.74	**	-0.37	**
Available Phosphorous	0.51	**	-0.53	**	-0.41	**
Exchangeable Potassium	0.43	**	-0.72	**	-0.26	NS
Cation exchange capacity	0.6	**	-0.67	**	-0.43	**

Where * = p≤ 0.05, ** = p ≤ 0.01, ns = non- significant at p< 0.05, r = correlation for number of observations and n = 48.

In terms of depth and distance, outer soil DB, pH, and EC were positively correlated with soil depth and stem radial distance, while other selected soil parameters such as MC, SOC, total N, soil Av, soil P, K, and CEC negatively correlated soil depth and distance from the tree trunk.
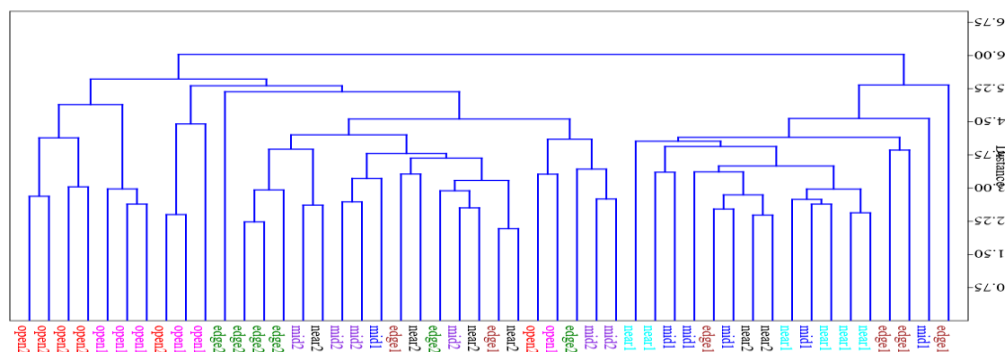
Figure 14. Dendrogram results from UPGMA method of hierarchical cluster analysis of soil properties under radial distance and soil depth under tree canopy and open land

Where surface (near1=0.5m, mid1= 2.5m, edge1=5m, and open1=15m) and subsurface (near2=0.5m, mid2= 2.5m, edge2=5m, and open2=15m) distance from tree trunk.

Hierarchical cluster analysis was used to detect similarities based on Euclidean distance using an unweighted pair group. The multivariate analysis method (UPGMA) examined the effects of canopy cover on soil properties as a function of radial distance coefficients and produced a dendrogram that grouped the variables into two statistically significant groups (Figure 4). Group 1 (near, center and edge) and Group 2 (open) corresponded to high and low soil fertility, respectively (Fig. 4). The factors found indifferent groups were shown to have significantly different effects on soil properties. Hierarchical group 1 (closed, medium and angular) and group 2 (open) matched in their floor-like effect. The range of dissimilarity was from 1.5 to 5.15, suggesting that data found near a shorter distance is more similar as it moves over a longer distance, where dissimilarity increases. Overall, two distinct sets of soil parameters under the canopy of Balanites aegyptiaca and open agricultural land were observed from the dendrogram.
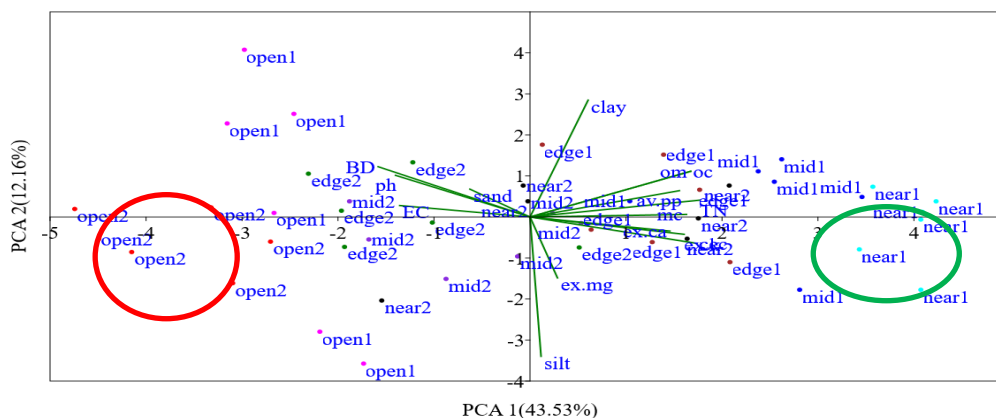
Figure 15. PCA of soil properties values based on radial distance and soil depth under the *Balanites aegyptiaca* tree canopy and open and. Where surface (near1=0.5m, mid1= 2.5m, edge1=5m, and open1=15m) and subsurface (near2=0.5m, mid2= 2.5m, edge2=5m, and open2=15m) distance from tree trunk

Principal Component Analysis (PCA) in a scatterplot shows the most important characteristics of a data set. For each factor, a saturation of the principal component greater than 1 was considered significant, indicating that two components explain 63.16% of the total variance (Figure 16). The first component contributed 51.51% to the variability of soil parameters near the trunk TN, OC, OM, CEC and Av. P had the highest loadings. The second component represents 11.65% of the total variability and is characterized by the texture of clayey loam soils with high loads. Overall, the principal component analysis confirmed the ANOVA result and visually demonstrated from the figure that the *Balanites aegyptiaca* tree affects soil properties under canopy and open agricultural land. Similar to this study, many researchers use multivariate analysis to assess natural variation, such as Khaledian *et al.* (2016), in "Assessing and Monitoring Land Degradation while Land Use Change Using Multivariate Analysis", presented the variability by clustering and PCA. By combining the results of PCA analysis, clustering and general soil analysis presented in this chapter, it is possible it can be concluded with certainty that Balanites aegyptiaca has a positive influence on soil properties under the tree canopy and that its effects are not felt outdoors. This can be explained by the shedding of leaves and the tree's climate-improving effect on the soil. These results also explain why sesame yields are higher under the tree than outside the trees.

4. Conclusion and Recommendations

4.1. Conclusion

Agroforestry in parks benefits dryland agricultural practices. Cultivation methods of the sesame tree Balanites aegyptiaca were investigated with regard to effects on yield and yield components as well as some soil properties in the lowlands of north-western Ethiopia. A higher mean grain yield was observed under the influence of the canopy than in the field, which is attributed to additional nutrients in the form of leaf litter, root renewal and excreta, and nitrogen fixation.

Soil bulk density was significantly lower in the surface layer under the canopy of *Balanites aegyptiaca* than in the surface and near-surface layers and increased with increasing radial distance from the tree trunk. The exchange capacity of soil organic carbon, total nitrogen, available phosphorus, potassium, and cations for the surface and subsurface soil layers under *Balanites aegyptiaca* was significantly better than outside the canopy.

Overall, the *Balanites aegyptiaca* Park agroforestry system is very important to improve soil fertility for sesame plant productivity, especially for poor farmers who do not have access to and cannot afford mineral fertilizers. But sometimes farmers remove trees because they are difficult to operate with a tractor. Either you keep the trees and plant them in rows, making it easier to use the tractor, or you develop tree-friendly farming technologies, excluding tractors.

Finally, as a universal tree, *Balanites aegyptiaca* added a significant amount of nutrients to the soil. Thus, the conservation of these important tree species on agricultural land has played a positive role in restoring soil fertility in households with limited resources to limit changes in mineral fertilizers.

4.2. Recommendations

The research results enable us to draw the following recommendations:

(i) Scattered *Balanites aegyptiaca* trees in agricultural landscapes have been shown to have a positive impact on soil fertilities compared to monolithic agricultural systems. Therefore, there is a need to extend the practice of agroforestry to resource-poor farmers to improve soil nutrients, improve microclimates, combat climate change, and other purposes. Eventually, due to its effect on enhancing land fertility and yield of associated crops either directly or indirectly, further research should be required on temporal and spatial distribution of fine root of *Balanites aegyptiaca* trees.

(ii) Litter quality is one of several factors affecting soil fertility which is established on type and nutrient contents of the litter. Therefore, further investigation is needed on *Balanites aegyptiaca* tree litter productivity, decomposability and its compositions.

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